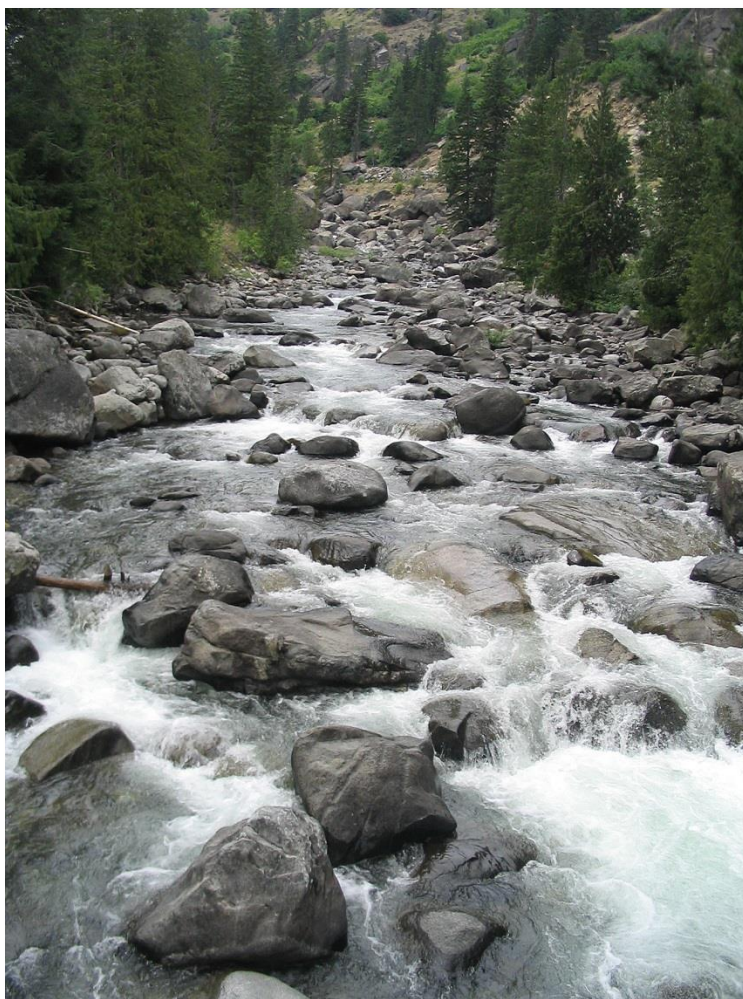


U.S. Fish and Wildlife Service

Summary of Icicle Creek Temperature Monitoring, 2014



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On the cover: *Icicle Creek upstream of the Leavenworth National Fish Hatchery. USFWS.*

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SUMMARY OF ICICLE CREEK TEMPERATURE MONITORING, 2014

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SUMMARY OF ICICLE TEMPERATURE MONITORING, 2014

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Executive Summary—The Mid-Columbia River Fisheries Resource Office began monitoring water temperature in Icicle Creek in 2005 to evaluate the impact of Leavenworth National Fish Hatchery (NFH) operations on stream temperatures. Temperature loggers were deployed at 13 sites in Icicle Creek upstream, adjacent to, and downstream of the Leavenworth NFH. In Icicle Creek water warms as it moves downstream, with two exceptions the Snow Creek confluence and the Leavenworth NFH spillway pool. Snow Creek receives water from a diversion drawing from the bottom of Snow Lake during the summer months and water in Snow Creek had a high 7DADMax 1.7 °C cooler than water temperatures recorded 0.1 km upstream in Icicle Creek. The spillway pool at Leavenworth NFH receives hatchery effluent river water mixed with well water creating an off-channel pool with a high 7DADMax that was 0.9 °C cooler than in Icicle Creek directly upstream of the Leavenworth NFH. At both locations Icicle Creek water temperatures were reduced by Leavenworth NFH operations. In 2014, air temperatures were within +/-1 standard deviation from the long-term mean.

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Introduction

Water temperature is extremely influential in the life history of fishes (Coutant 1987; Magnuson et al. 1979; Olden and Naiman 2010). Icicle Creek is home to ESA-listed Bull Trout *Salvelinus confluentus*, anadromous Rainbow Trout *Oncorhynchus mykiss* (commonly known as steelhead) and spring Chinook Salmon *Oncorhynchus tshawytscha*. These fish are considered coldwater species and have upper thermal limits for rearing, spawning and adult survival (Brett 1952; Bell 1986; Fraley and Shepard 1989; Eaton and Scheller 1996; Rieman and Chandler 1999; Myrick and Cech 2001; Dunham and Chandler 2001; Selong et al. 2001; WAC 173-201A-602). Monitoring water temperature in Icicle Creek is critical to determine whether Leavenworth NFH operations adversely impact Icicle Creek water temperatures which may degrade the thermal habitat for ESA-listed species.

This report summarizes water temperature data collected by the Mid-Columbia River Fisheries Resource Office in Icicle Creek and tributaries upstream, adjacent to, and downstream of the Leavenworth National Fish Hatchery (NFH) in 2014. Water temperature monitoring sites were unchanged from the previous years. Temperature data in this report encompassed all of 2014, however the focus was on the period of the warmest water temperatures which occurred during the summer months.

Study Area

The Icicle Creek watershed drains 55,426 hectares of forested uplands on the eastern slope of the Cascade Mountain range in North Central Washington State. Icicle Creek is 50.8 km long from its headwaters at Lake Josephine at an elevation 1423 m to its confluence with the Wenatchee River at an elevation of 340 m (WRWSC 1998). Upstream of river kilometer (rkm) 6.0 Icicle Creek watershed is characterized by high basin relief, glaciated cirques, and steep headwalls, with batholithic geology. Downstream from rkm 6.0 to the mouth of Icicle Creek the watershed forms a shallow gradient basin filled with sand-and-gravel based glacial deposits. Approximately 87% of the watershed is publically owned and maintained by the U.S. Forest Service with 74% of the watershed residing within the Alpine Lakes Wilderness (USFS 1994).

The Icicle Creek watershed receives 305 cm of precipitation at the highest elevations, and 50.8 cm in the lower elevations. There are 14 glaciers and 102 lakes in the watershed that store most of the available precipitation, with glacial melt estimated to generate 21% of Icicle Creek flow during the summer months (Mullen et al. 1992). Stream discharge was recorded by the U.S. Geological Survey (#12458000) located at rkm 9.4 during two intervals, first from 1936–1971 and then from 1993 to the present. Mean base flow from 1937–2014 was 291cfs. The minimum discharge was 44 cfs and occurred on November 30, 1936; the maximum discharge was 19,800 cfs and occurred on November 29, 1995.

Icicle Creek has two major water diversions that impact in-stream flow and water temperature (Figure 1). Both diversions occur near the confluence of Snow Creek and each diversion supplies two user groups. Upstream of the Snow Creek confluence at rkm 9.3, the Icicle Peshastin Irrigation District (IPID) withdraws 60–103 cfs of water from April through September, and the City of Leavenworth withdraws 2 cfs year-round (Montgomery Water Group, Inc. 2004). Downstream of Snow Creek at rkm 7.2, the Cascades Orchard Irrigation Company (COIC) withdraws 7 cfs from May– September, and the Leavenworth NFH uses 20–40 cfs year-round. The total amount of water diverted by all users from Icicle Creek during the summer months of June, July, and August, is about 140 cfs, while in the winter months it is about 42 cfs. (Montgomery Water Group, Inc. 2004).

Snow Creek is a major tributary of Icicle Creek, joining at rkm 9.2. Snow Creek drains a series of high mountain lakes; Upper Snow Lake is the largest by volume at approximately 12,450 acre-ft at full capacity (Anchor QEA 2010). In 1939, the U.S. Bureau of Reclamation installed a valve near the bottom of Upper Snow Lake to drain the lake at a controlled rate and supplement Icicle Creek during low-flow periods. Leavenworth NFH has rights to 16,000 acre-ft of water per year from Upper Snow Lake. The valve is typically opened in late July delivering up to 60 cfs of water to Snow Creek, and is closed in October (Table 1). During some low-flow periods, supplemented Snow Creek water represents the majority of in-stream flow in Icicle Creek after the IPID diversion.

The Leavenworth NFH occupies land adjacent to Icicle Creek from approximately rkm 4.1 to rkm 6.1. Icicle Creek watershed transitions from a steep canyon to a broad valley at rkm 6.1. Downstream of the Leavenworth NFH, Icicle Creek meanders for 4.0 rkm through a broad valley of mixed residential and agricultural properties before its confluence with the Wenatchee River.

The Leavenworth NFH water intake is located in Icicle Creek at the shared COIC/LNFH diversion at rkm 7.2, and water was transported to the hatchery via underground piping. The Leavenworth NFH also uses up to 14.4 cfs of well water in addition to the river water however average use is about 4 cfs. Well water temperatures are between 7–9 °C year-round and are used to cool incubation racks and rearing water in the summer and warm them in the winter (USFWS 2006).

The Leavenworth NFH returns water to Icicle Creek in two locations: 1) the adult fish ladder outfall at rkm 4.3, which drains the adult and juvenile rearing ponds, and 2) the pollution abatement pond at rkm 4.2. More than >95% of the water that the Leavenworth NFH uses is returned to Icicle Creek via the adult fish ladder outfall. Water is released from the pollution abatement pond at a rate of approximately 1 cfs with a daily pulse of about 3 cfs for a few hours during routine juvenile pond cleaning (Hall 2013). In 2011, the Leavenworth NFH began using a new abatement pond (AB2) while the old pond (AB1) was refurbished. Both ponds have been used since 2014, however, only AB2 was monitored in 2014.

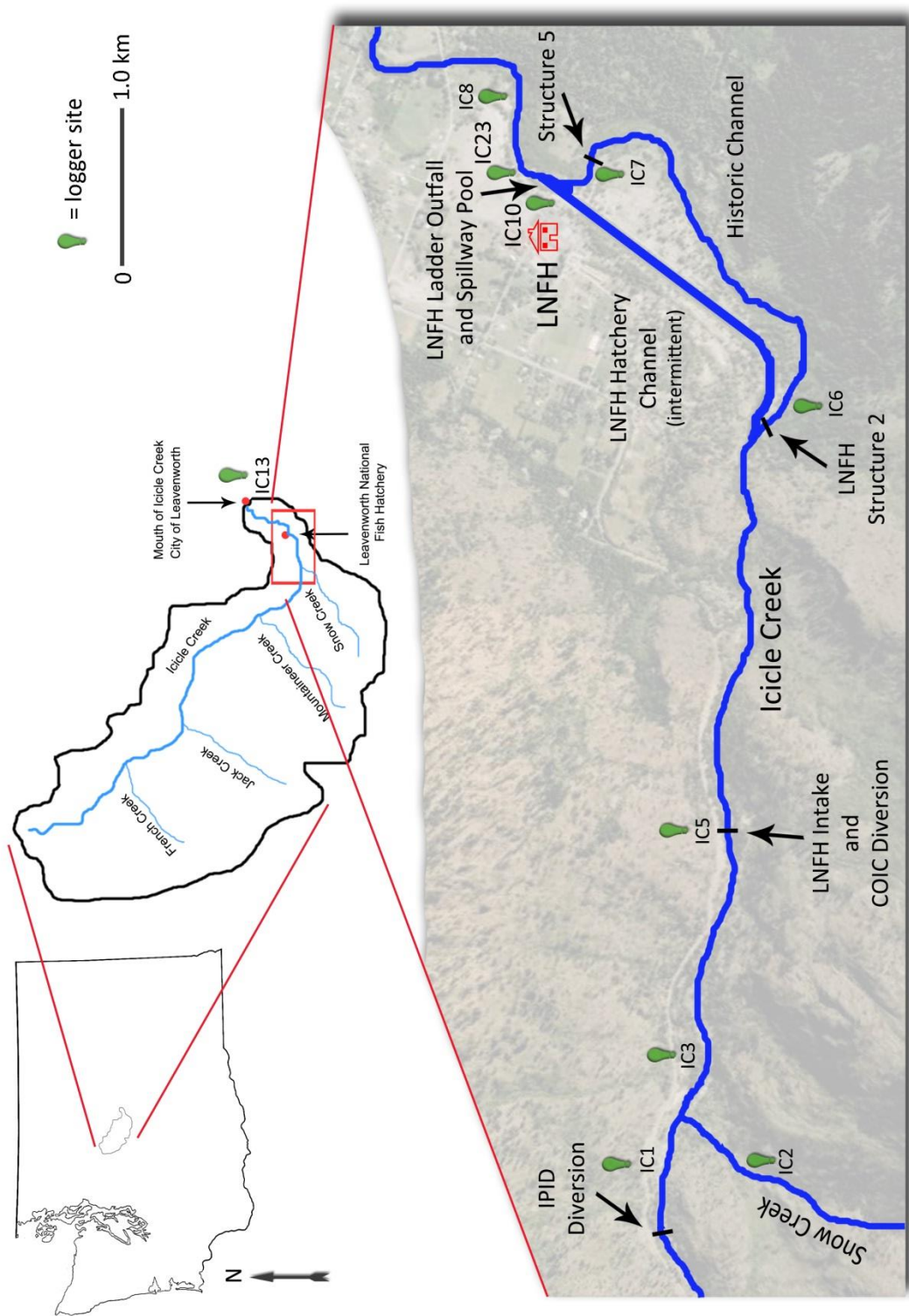


FIGURE 1.—Map of Icicle Creek drainage with *selected* water temperature monitoring sites and structures.

TABLE 1.— Snow Lake valve openings, adjustments, closures, and discharge into Snow Creek, 2006–2014.

Year	Date	Action	Discharge ¹
2014	31-Jul	Valve opened	50 cfs
	24-Aug	Adjustment	Increased to 55 cfs
	2-Oct	Valve Closed	
2013	25-Jul	Valve opened	40 cfs
	31-Aug	Adjustment	increased approx. 15 cfs
	3-Oct	Valve closed	
2012	31-Jul	Valve opened	25 cfs
	10-Aug	Adjustment	increased to 50 cfs
	28-Aug	Adjustment	opened from 45 to 53 degrees
	2-Oct	Valve closed	
2011	3-Aug	Valve opened	20 cfs
	12-Aug	Adjustment	opened to 30+ degrees
	31-Aug	Adjustment	opened to 47 degrees
	3-Oct	Valve closed	
2010	2-Aug	Valve opened	32 cfs
	13-Aug	Adjustment	increased to 53 cfs
	27-Aug	Adjustment	increased to 60 cfs
	4-Oct	Valve closed	
2009	23-Jul	Valve opened	14 cfs
	27-Jul	Adjustment	increased to 32 cfs
	10-Aug	Adjustment	increased to 52 cfs
	10-Sep	Adjustment	increased to 60 cfs
	6-Oct	Valve closed	
2008	29-Jul	Valve opened	25 cfs
	12-Aug	Adjustment	increased to 60 cfs
	3-Oct	Valve closed	
2007	23-Jul	Valve opened	53 cfs
	3-Oct	Valve closed	
2006	26-Jul	Valve opened	18 cfs
	16-Aug	Adjustment	increased to 56 cfs
	5-Oct	Valve closed	

¹Discharge is a function of both valve opening and head pressure (level of the lake). If the valve is left in the same position, discharge will decrease as head pressure decreases (Wurster 2009).

Methods

Water Temperature

In 2014, water temperature monitoring continued throughout the year at the same 13 sites as previous years (Appendix A). Water temperature at all sites was recorded with Hobo Water Temp Pro V2 temperature loggers. All loggers were programmed to record water temperatures hourly.

In 2014, all water temperature monitoring sites were visited three times to download data and perform routine maintenance. On April 3, all of the loggers were brought in from the field for data downloading, cleaning and calibration. The loggers were re-deployed on April 8 (Appendix B). On August 5 and October 28, data were downloaded in the field and the loggers were not removed. During each visit the housing and loggers were cleaned and the cables were inspected for integrity.

Water temperature comparisons between sites and across the summer season were done using a 7-day average of the daily maximum temperatures (highest 7DADMax). The highest 7DADMax is the mean of seven consecutive daily maximum temperatures calculated using the day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after. For example the high 7DADMax for August 6 would be the mean of the daily maximum temperatures for August 3–9. The highest 7DADMax is considered a better metric to evaluate stream water temperature than daily max temperatures because it is not overly influenced by a single high daily temperature rather it describes the fishes exposure to a week-long average high temperatures (USEPA 2003).

On October 28, 2014, IC3 located on Icicle Creek directly below the confluence with Snow Creek was not recovered. A second attempt on January 14, 2015 also failed to recover the logger. Another temperature logger was deployed at IC3 when spring flows came down in 2015. IC10, located in the Leavenworth NFH spillway pool, was found out of the water when it was retrieved for downloading on August 5. The data showed that the logger was removed from the water on July 9. No data from IC10 prior to August 5, 2014 was used in the results for this report. IC11 was also located in the spillway pool and was used to represent the spillway pool water temperatures in 2014.

Air Temperature

Air temperature data were downloaded from the Washington Department of Ecology "River and Stream Flow Monitoring" website (<https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp>, station ID: 45B070, "Icicle Cr. Near Leavenworth"). Prior to 2012, air temperature data were recorded at the Mid-Columbia River Fisheries Resource Office (rkm 5.0), using Hobo Water Temp Pro V2 temperature loggers.

Results

Note that because IC3 and IC10 are missing data from the summer period, daily max and 7DADMax were not calculated for these sites. Data collected from this project are available upon request.

Water Temperature

In 2014, water temperatures in Icicle Creek varied temporally and spatially (Figure 2; Table 2). Downstream monitoring sites were warmer than more upstream sites with the exception of IC5 which is located in Icicle Creek directly downstream of the Snow Creek confluence and IC11 located in the Leavenworth NFH spillway pool. IC5 recorded lower temperatures than upstream sites after Snow Lake supplementation because Snow Creek flows into Icicle Creek upstream of IC5. The high 7DADMax for IC5 was 18.3 °C and occurred the day before Snow Lakes opened. The high7DADMax for IC5 after Snow Lakes was opened was 17.8 °C. The warmest site on Icicle Creek was IC13 located at the mouth and had a high 7DADMax of 18.8 °C and a daily high of 19.5 °C.

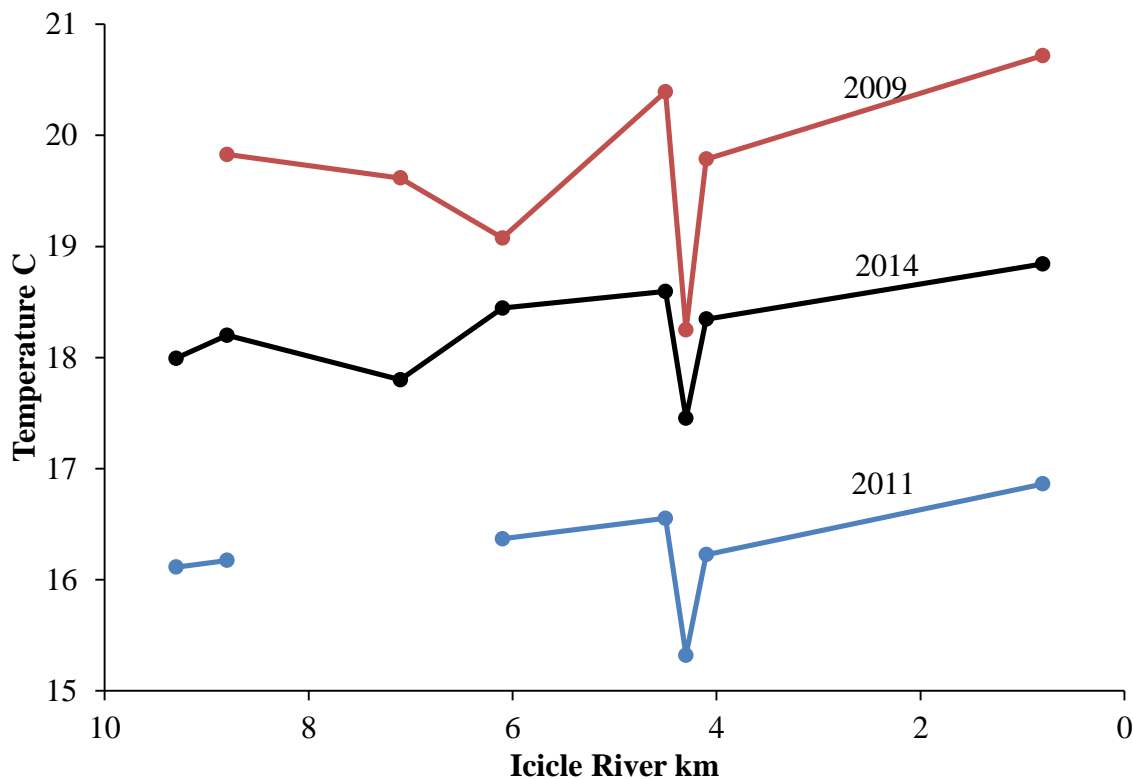


FIGURE 2.— Water temperature profile of Icicle Creek from river kilometer (rkm) 9.3 downstream to the mouth (rkm 0). The high 7DADMax for 2014 (black) compared to 2009 (red) and 2011 (blue), respectively, the warmest and coolest year since monitoring began in 2005.

TABLE 2.— Highest 7DADMax water temperatures recorded at each site, the date the temperatures were reached and the river kilometer (rkm) of each site.

Site	Description	Elevation (m)	rkm	Date	Highest 7DADMax °C
IC19	Upstream of IPID @ USGS gauge	435	9.3	8/6	18.0
IC1	Upstream of Snow Creek	410	8.8	8/6	18.2
IC2	Snow Creek	398	- -	8/1	16.3 ¹
IC5	LNFH intake	356	7.1	8/1	18.3
IC6	LNFH headgate (structure 2)	350	6.1	8/1	18.4
IC7	Downstream of structure 5	340	4.5	8/1	18.6
IC11	LNFH spillway pool	340	4.3	8/1	17.5
IC23	Abatement pond	339	4.2	8/1	18.4
IC8	Icicle downstream of LNFH	339	4.1	8/1	18.3
IC13	Icicle Mouth	334	0.8	8/1	18.8
IC15	Wenatchee River	339	- -	8/1	19.8

1) Snow Creek 7DADMax was calculated after supplementation from Snow Lake.

Snow Creek Supplementation

Supplementation of Snow Lakes water into Icicle Creek via Snow Creek began on July 31 which was slightly later than the previous average opening date of July 28 (2006–2013). During supplementation water temperatures in Snow Creek had a high 7DADMax of 16.3 °C which was 1.7 °C cooler than the main-stem Icicle Creek 0.1 rkm upstream from the confluence (Table 2). After supplementation begins, Snow Creek temperatures decrease continuously for the remainder of the year (Figure 3). The decrease in Snow Creek temperatures was consistent with data from previous years. On July 31, 2014 the valve at Snow Lakes was open to provide 50 cfs of flow, when flows in Icicle Creek above the Snow Creek confluence were 342 cfs (Figure 4). On August 24, 2014 the valve was open further to provide 55 cfs when Icicle Creek flows were at 211 cfs. The valve was closed on October 2, 2014 when flows were 137 cfs. During this period Leavenworth NFH was removing 42 cfs from Icicle Creek at the in-take (S. Croci, LNFH, personal communication).

In previous reports, the effects of Snow Lakes supplementation was highlighted by comparing IC3, which was located in Icicle Creek immediately downstream of the Snow Creek confluence, to IC1 which was located in Icicle Creek 0.1 rkm upstream of the Snow Creek confluence. However, in 2013 and 2014, data from the summer months at IC3 was not available. Previous reports showed that IC3 was, on average, 0.6 °C cooler than IC1 (range 0.2–1.0 °C) during the summer months due to supplementation. In 2013 and 2014, the effects of Snow Lakes supplementation was shown by comparing IC1 to IC5 which was located approximately 2 rkm downstream of the Snow Creek confluence. In 2014, IC5 had a high 7DADMax that was 0.2 °C cooler than IC1 during supplementation, demonstrating the cooling effect of Snow Lakes (Figure 2).

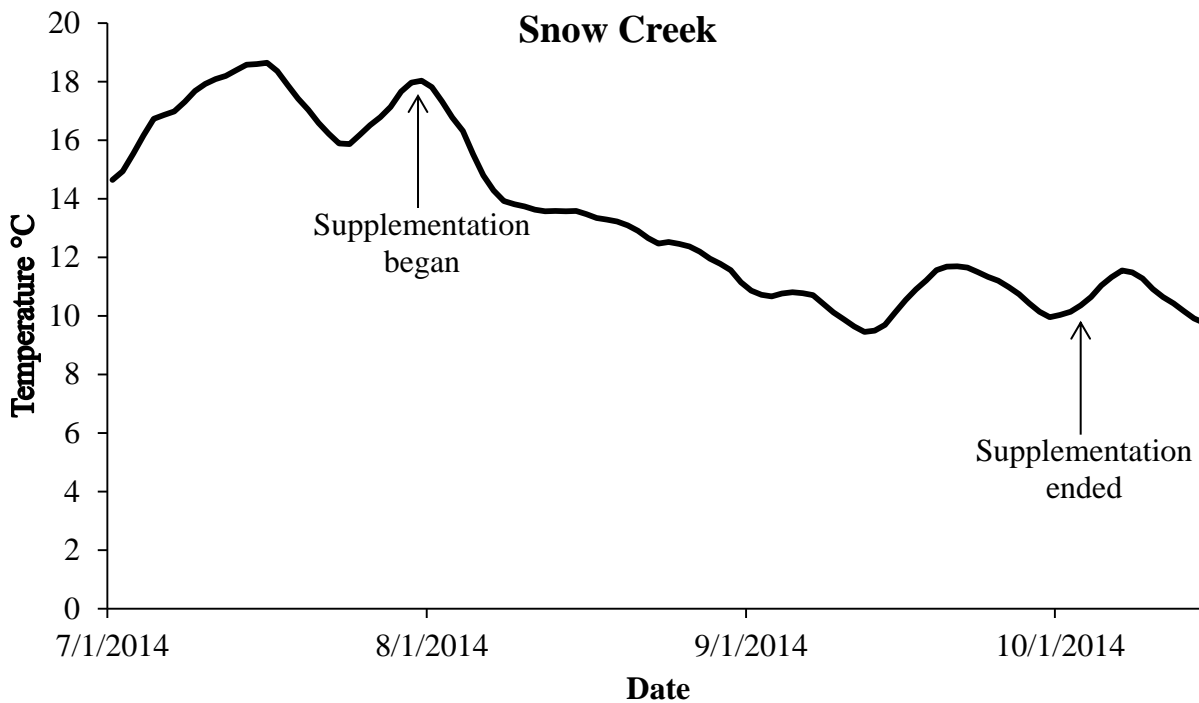


FIGURE 3.— Mean daily water temperature of Snow Creek from July 1–October 15, 2014 demonstrating the cooling effects of supplementation from 50–55cfs of cool water from Snow Lake.

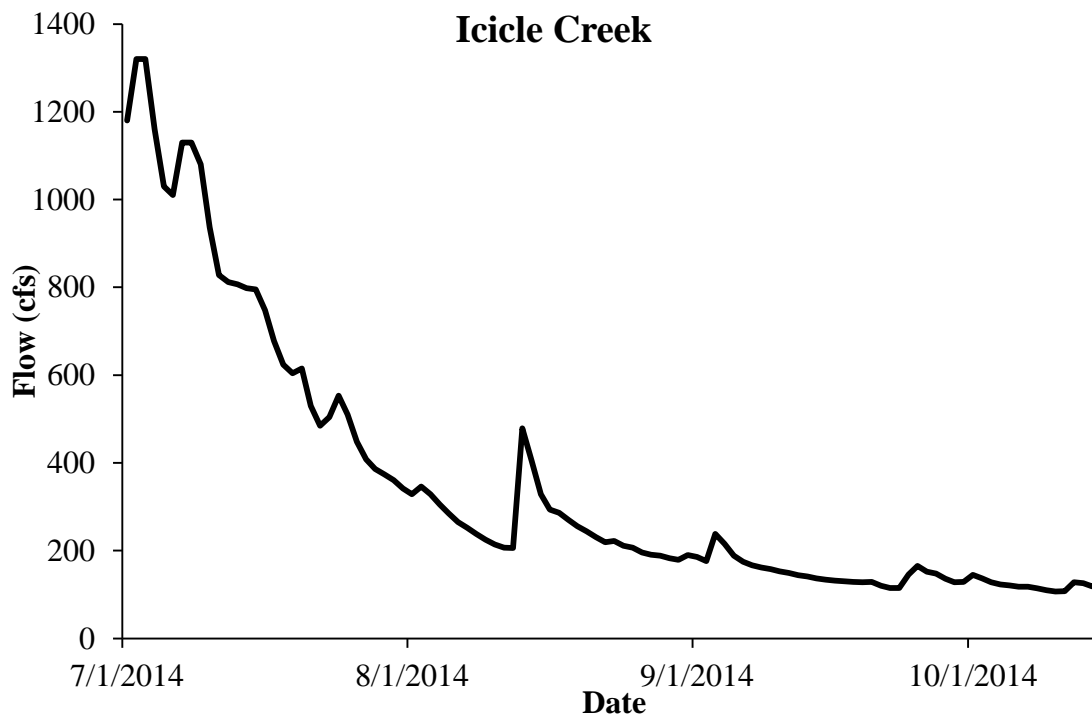


FIGURE 4.— Mean daily flow in Icicle Creek from July 1–October 15, 2014 measured at the U.S. Geological Survey gauge #12458000, upstream of the Snow Creek confluence.

Spillway Pool and Ladder Outfall

The Leavenworth NFH spillway pool is an off-channel pool formed by the intermittent use of the Hatchery Channel and the adult fish ladder outfall (Figure 1). More than 95% of the water that Leavenworth NFH returns to Icicle Creek enters at the spillway pool. The returned river water was often mixed with well water, which is between 7–9 °C, depending on which well is used. Water temperature sites IC10 and IC11 represent different locations within the Leavenworth NFH spillway pool. IC11 is directly under the Leavenworth NFH adult ladder drain on river left, while IC10 is on the opposite side of the pool. In 2014, IC10 data logger was missing data from the summer months. However, in previous years water temperatures recorded at IC10 and IC11 differed by only 0.1 °C so IC11 was used to represent the spillway pool.

In 2014, IC11 recorded the lowest high 7DADMax and daily max of all the monitoring sites at 17.5 °C and 18.0 °C, respectively. Since water temperature monitoring began in Icicle Creek 7DADMax temperatures at the spillway pool have been the lowest among the sites. In 2014, IC11's high 7DADMax and daily max were 1.1 °C and 1.9 °C, cooler than IC7 which is located immediately upstream (Figure 2). IC11 recorded lower temperatures than sites upstream which demonstrated that Leavenworth NFH operations reduced Icicle Creek during summer months. In contrast, during the winter, the well water increased the temperature of discharged water from Leavenworth NFH by up to 2.9 °C when compared with IC7 (Hall and Kelly-Ringel 2011). The summer cooling and winter warming was directly attributed to the operational influence of the Leavenworth NFH. During periods of low flow, the spillway pool was distinctly separated from the thalweg of Icicle Creek and mixing occurred downstream of the spillway pool. During high flows, the Icicle Creek flowed over the bank and into the spillway pool which resulted in water mixing further upstream than during low flow periods.

Abatement Pond

The Leavenworth NFH abatement pond returned about 1cfs of water to Icicle Creek during most of the year with the exception of a few hours each day when cleaning activities increased the flow to approximately 3 cfs (Hall 2013). In 2014, the high 7DADMax was 18.4 °C, and the daily max was 19.1 °C. The discharge from the abatement pond was warmer than the nearest upstream Icicle Creek site, IC11 the spillway pool. However, a comparison to IC11 is misleading because water in IC11 was tempered with well water. When compared to Icicle Creek above Leavenworth NFH the abatement discharge was cooler because it receives effluent from the hatchery that was tempered by well water which offset the solar heating in the abatement pond. Additionally, the contribution from the abatement pond was small (~1 cfs). The high 7DADMax of 18.4 °C in 2014 was slightly below the mean high 7DADMax from 2006–2013 of 19.0 °C.

Air Temperature

In 2014, Icicle Creek experienced erratic air temperatures however; the majority of the year the mean was within ± 1 standard deviation calculated using the period of record 2006–2013 (Figure 5). The mean summer air temperature was 21.9°C , the high 7DADMax was 27.3°C , and occurred on July 14 (Figure 6).

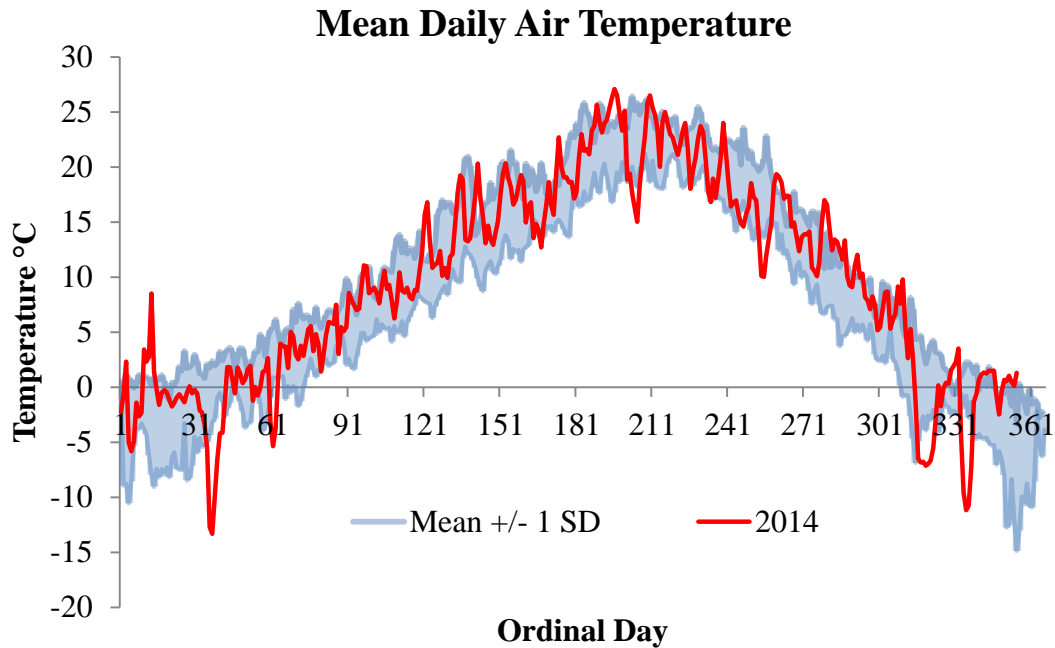


FIGURE 5.— Mean daily air temperature, 2014 and 2006–2013 (± 1 SD).

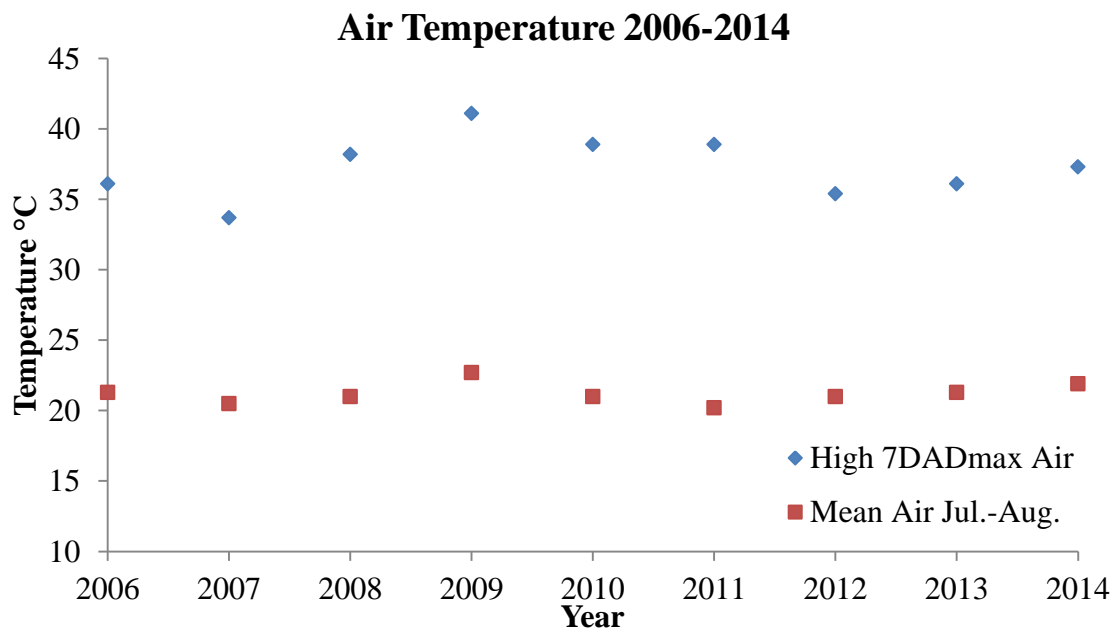


FIGURE 6.— Mean summer and high 7DADMax air temperature for 2006–2014.

Discussion

Water temperatures during the summer months in Icicle Creek were reduced by Leavenworth NFH operations. Water temperature monitoring across 9.3 rkm in Icicle Creek indicated a downstream warming trend with the exception of two locations; downstream of the Snow Creek confluence (IC5) and the Leavenworth NFH spillway pool (IC11). Both locations consistently recorded lower water temperatures than sites immediately upstream and both were direct results of Leavenworth NFH operations. In 2014, the influence from Snow Creek supplementation provided up to 50 cfs of water that was 1.7 °C cooler than Icicle Creek when water temperature in Icicle Creek was increasing and flow was decreasing. The impact of Snow Creek water supplementation increases throughout the summer months because flow in Icicle Creek decreases which results in a higher percentage of Icicle Creek flow composed of cooler water from Snow Creek supplementation. Additionally, water temperatures in Snow Creek declined throughout the period of supplementation, likely because of both decreasing air temperatures and decreasing flow from the natural Snow Creek source which was the warm surface water of Snow Lake. The effects of well water use were demonstrated by decreased water temperatures in the spillway pool that were out of sync with the downstream warming trend. Well water used by the hatchery to temper rearing and incubation of spring Chinook Salmon resulted in cooler water temperatures. The only source of increased water temperatures connected to hatchery operations was the warm water discharged from the abatement ponds. However, when compared to Icicle Creek water temperatures upstream of the Leavenworth NFH the abatement pond water was cooler. Regardless of the water temperature in the abatement pond the impact of discharge from the abatement pond was negligible because flows were low, on average 1 cfs. Leavenworth NFH operations did not reduce flow in Icicle Creek during the summer months. Snow Creek supplementation of 50–55cfs enters Icicle Creek 1.6 rkm upstream of the Leavenworth NFH intake. At the in-take the hatchery removes 42 cfs so the flow below the intake represented the natural flow of Icicle Creek.

The life histories of ESA-listed Bull Trout, steelhead and spring Chinook Salmon are known to be impacted by water temperatures. Each species has upper thermal limits for rearing, spawning and adult survival therefore reducing water temperatures should not negatively impact stream conditions for these coldwater species (Appendix C). Although water temperatures recorded in 2014 indicated that Icicle Creek may not be thermally suitable for some life history stages of these species lethal water temperatures were never reached. Bull Trout water temperature requirements are cooler than those of steelhead and Chinook Salmon (WAC 173-201A-602). The Washington State Department of Ecology criterion for Bull Trout rearing is a high 7DADMax of 12 °C (WAC 173- 201A-602). Juvenile Bull Trout are uncommon where water temperatures exceed 15 °C for extended periods of time and adult bull trout prefer 9–13 °C (Fraley and Shepard 1989; Rieman and Chandler 1999; Dunham and Chandler 2001; Selong et al. 2001; WAC 173-201A-602). These water temperature criteria were not always met indicating that Icicle Creek may not be thermally suitable for some life history stages of Bull Trout. However, the upper lethal limit to adult Bull Trout is a high 7DADMax of 23.5 °C and was not recorded in Icicle Creek during 2014 (Selong et al. 2001). Nelson et al. (2011) suggested that the spillway pool which was cooled by Leavenworth NFH discharge may serve as a thermal refuge for Bull Trout in Icicle Creek when water temperatures are high. The high 7DADMax WDOE criteria for

rearing of salmonid spawning, rearing, and migration is 17.5 °C (WAC 173- 201A-602). In 2014, this criterion was only met in the spillway pool again indicating that Leavenworth NFH operations did not negatively impact the stream temperature regime for native salmonids. Studies have shown the upper thermal limit for Chinook Salmon is a high 7DADMax between 24.0–25.1 °C (Brett 1952; Bell 1986; Eaton and Scheller 1996; Myrick and Cech 2001). Temperatures lethal to steelhead have been documented as a high 7DADMax of 21.0–23.9 °C (Bell 1986; USEPA 1999). In warm water years with low flows the reduction in water temperatures from Leavenworth NFH operations may help to avoid lethal water temperatures for these coldwater species

In conclusion, water temperature monitoring data in 2014 indicated that water temperatures in Icicle Creek were lower as a result of Leavenworth NFH operations. Cooler water temperatures may benefit native coldwater fishes such as Bull Trout, steelhead and Chinook Salmon and in warmer water years the Leavenworth NFH spillway pool may provide thermal refuge for native fishes.

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Appendix A: Site Descriptions, elevation, High 7DADMax, High Max, and Date of first occurrence.

Table A1. Site Descriptions, elevation, High 7DADMax (°C), Daily Max Temperature (°C), and Date of first occurrence.

Site	Description	rkm	Elevation (m)	Year	High 7DADMax	7DADMax week ending	Daily Max Temperature	Date of Daily Max Temperature
IC15	Wenatchee River	n/a	339	2014	19.8	2-Aug	20.9	16-Aug
				2013	no data	no data	no data	no data
				2012	19.7	20-Aug	20.2	19-Aug
				2011	17.9	30-Aug	18.1	27-Aug
IC13	Icicle Mouth	0.8	334	2014	18.8	2-Aug	19.7	2-Aug
				2013	19.2	11-Aug	20.4	10-Aug
				2012	18.2	19-Aug	18.7	8-Aug
				2011	16.8	29-Aug	17.2	29-Aug
				2010	18.1	18-Aug	18.7	17-Aug
				2009	20.7	3-Aug	21.3	1-Aug
				2008	18.7	19-Aug	19.4	16-Aug
				2007	18.8	29-Jul	19.4	26-Jul
IC23	Abatement Pond outfall	4.2	339	2014	18.4	2-Aug	19.1	2-Aug
				2013	17.9	12-Aug	19.6	11-Aug
				2012	16.5	9-Aug	17.5	8-Aug
				2011	20.2	7-Jul	22.7	5-Jul
				2010	no data	no data	no data	no data
				2009	22	2-Aug	23	29-Jul
				2008	19.4	19-Aug	20.5	19-Aug
				2007	18	15-Jul	19	4-Aug
IC8	d/s of LNFH	4.1	339	2014	18.3	2-Aug	19.0	2-Aug
				2013	18.5	27-Jul	19.6	10-Aug
				2012	no data	no data	no data	no data
				2011	16.2	29-Aug	16.5	29-Aug
				2010	no data	no data	no data	no data
				2009	19.8	3-Aug	20.3	28-Jul
				2008	no data	no data	no data	no data
				2007	19.4	26-Jul	18.5	26-Jul
				2006	18.9	27-Jul	19.8	23-Jul
				2005	19.6	31-Jul	20	28-Jul
IC11	LNFH at Ladder outfall	4.3	340	2014	17.5	2-Aug	18.0	2-Aug
				2013	17.1	27-Jul	17.9	10-Aug

				2012	16.6	9-Aug	17.3	5-Aug
				2011	15.3	29-Aug	15.4	25-Aug
				2010	no data	no data	no data	no data
				2009	18.2	2-Aug	18.7	28-Jul
				2008	16.3	19-Aug	17	16-Aug
				2007	16.3	29-Jul	16.8	26-Jul
IC10	LNFH Spillway pool	4.3	340	2014	no data	no data	no data	no data
				2013	no data	no data	no data	no data
				2012	16.4	18-Aug	17.3	8-Aug
				2011	15.2	29-Aug	15.4	23-Aug
				2010	no data	no data	no data	no data
				2009	18.3	2-Aug	18.7	28-Jul
				2008	16.2	19-Aug	16.8	16-Aug
				2007	16.2	30-Jul	16.8	26-Jul
				2006	no data	no data	no data	no data
				2005	16.9	11-Aug	17.7	31-Jul
IC7	d/s of Structure 5	4.5	340	2014	18.6	2-Aug	19.3	2-Aug
				2013	18.8	11-Aug	19.8	10-Aug
				2012	17.7	19-Aug	18.3	14-Aug
				2011	16.6	29-Aug	16.8	29-Aug
				2010	no data	no data	no data	no data
				2009	20.4	3-Aug	20.9	1-Aug
				2008	18.2	19-Aug	19.2	16-Aug
				2007	19.3	29-Jul	20.2	28-Jul
				2006	19.4	28-Jul	20.2	23-Jul
				2005	no data	no data	no data	no data
IC6	at LNFH Headgate	6.1	350	2014	18.4	2-Aug	19.2	2-Aug
				2013	18.4	27-Jul	19.4	10-Aug
				2012	17.5	18-Aug	18.2	8-Aug
				2011	16.4	29-Aug	16.5	23-Aug
				2010	17.3	18-Aug	17.7	17-Aug
				2009	19.1	2-Aug	19.6	28-Jul
				2008	17.6	18-Aug	18.6	16-Aug
				2007	17.9	30-Jul	18.8	26-Jul
				2006	19.2	28-Jul	20.2	23-Jul
				2005	20.3	21-Aug	21	16-Aug
IC5	LNFH Intake	7.1	356	2014	18.3	2-Aug	19.0	2-Aug
				2013	18.1	26-Jul	19.8	10-Aug
				2012	17.1	19-Aug	17.8	5-Aug
				2011	no data	no data	no data	no data
				2010	no data	no data	no data	no data

IC3	d/s of Snow Creek	8.7	392	2009	19.6	2-Aug	20.1	28-Jul
				2014	no data	no data	no data	no data
				2013	no data	no data	no data	no data
				2012	17	19-Aug	17.7	5-Aug
				2011	16	29-Aug	16.2	25-Aug
				2010	16.4	18-Aug	16.8	17-Aug
				2009	19.5	2-Aug	20	28-Jul
				2008	no data	no data	no data	no data
				2007	17.2	30-Jul	18.2	26-Jul
				2006	no data	no data	no data	no data
IC2	in Snow Creek	n/a	398	2005	18.1	31-Jul	18.6	29-Jul
				2014	16.3	2-Aug	18.9	2-Aug
				2013	17.1	23-Jul	18.4	2-Jul
				2012	18	19-Jul	18.5	19-Jul
				2011	15.6	8-Aug	16.4	4-Aug
				2010	17.4	30-Jul	18.3	28-Jul
				2009	18	28-Jul	18.7	27-Jul
				2008	15.9	26-Jul	16.7	9-Jul
				2007	18.5	16-Jul	19.7	13-Jul
				2006	17.5	14-Jul	19	14-Jul
IC1	u/s of Snow Creek	8.8	410	2005	16.6	23-Jul	17.4	18-Jul
				2014	18.0	2-Aug	18.8	9-Aug
				2013	18.3	11-Aug	19.1	10-Aug
				2012	17.6	20-Aug	18.2	14-Aug
				2011	16.2	29-Aug	16.4	25-Aug
				2010	17.4	18-Aug	18	17-Aug
				2009	19.8	2-Aug	20.2	28-Jul
				2008	18.3	19-Aug	19.3	16-Aug
				2007	17.9	29-Jul	18.7	2-Aug
				2006	18.6	27-Jul	19.5	23-Jul
IC19	u/s of IPID at USGS gauge	9.3	435	2005	18.9	31-Jul	19.5	6-Aug
				2014	18.0	9-Aug	18.7	9-Aug
				2013	18.3	10-Aug	18.9	10-Aug
				2012	17.7	19-Aug	18.2	14-Aug
				2011	16.1	29-Aug	16.4	25-Aug

Appendix B: Temperature Logger Calibration Protocol

Temperature Logger Calibration/ Testing
Kendall Henry

Prior to deployment temperature loggers were tested and calibrated. Temperature loggers were tested in two water baths representing the potential extremes temperatures of their monitoring conditions, as per Ward (2003).

Water baths were made in coolers and used either an aquarium powerhead or air pump/stone added to mix the water and maintain a uniform temperature. Temperature loggers were weighted in the coolers with the same nuts and bolts used in the field. Temperature loggers were acclimated to the water baths for at least 30 minutes before temperature monitoring began. To validate the temperatures we used a NIST certified thermometer and an YSI sonde. Temperature loggers were set to record temp at five minute intervals and the YSI and NIST temperatures were recorded at the same interval.

The room-temperature water bath was made by filling a cooler and allowing it to stabilize to room temperature (approx. 21 °C). The ice-water bath was made with tap water and ten trays of ice cubes. The lid was placed over the cooler except for 1 inch on the side to allow insertion of the thermometer and the power cord for the pump. The ice-water bath sat for at least one hour to allow it to stabilize and become uniform throughout.

After the tests concluded the data were analyzed. Temperature loggers were retested if an absolute value recorded differed by more than ± 0.2 °C. If the second test of a temperature logger showed similar results that logger was not used during this study.

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Appendix C: *ESA-listed Fishes*

TABLE C1.— Upper thermal water temperature criteria for Char and Salmonids.

Category	Highest 7DADMax °C
Char Spawning ¹	9.0
Char Spawning and Rearing ¹	12.0
Salmon and Trout Spawning ¹	13.0
Core Summer Salmonid Habitat ¹	16.0
Salmonid Spawning, Rearing, and Migration ¹	17.5
Salmonid Rearing and Migration Only ¹	17.5
Upper Lethal Limit Bull Trout ²	23.5
Upper Lethal Limit Steelhead ³	21.0–23.9
Upper Lethal Limit Chinook Salmon ⁴	24.0–25.1

1) WAC 173-201A-602

2) Selong et al. 2001

3) Bell 1986; USEPA 1999

4) Brett 1952; Bell 1986; Eaton and Scheller 1996; Myrick and Cech 2001

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